Impact of surface emissions on the zonal variability of tropical tropospheric ozone and carbon monoxide for November 2004

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Surface emissions and ozone

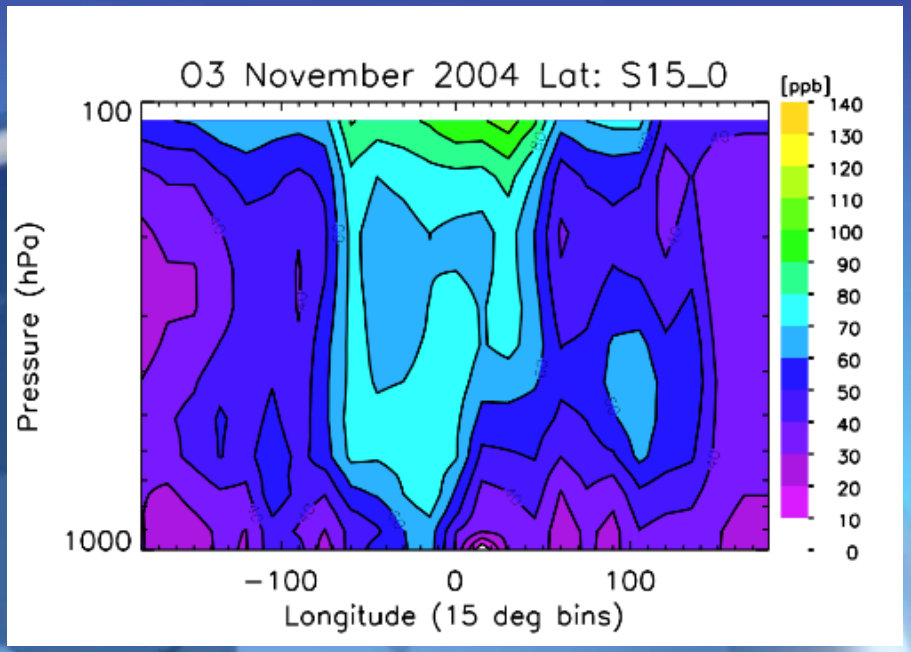
- Emissions from biomass burning and biofuel are the largest anthropogenic contributor of ozone precursors in the southern hemisphere
- The scale, distribution, and composition of these emissions are subject to large uncertainties
- Ascribing ozone formation to these emissions is complicated by significant natural sources of ozone and transport
- Satellite observations--in particular TES--can be combined with chemical transport models via estimation theoretic algorithms to
  - Determine both the magnitude and distribution of these emissions
  - Assess the impact of these emissions on the distribution of ozone
  - Investigate the processes linking emission source to ozone variability and distribution

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

TES nadir provide a unique capability to help understand these processes by providing simultaneous profile retrievals of both ozone and carbon monoxide along with temperature, water vapor, surface, and effective cloud properties.

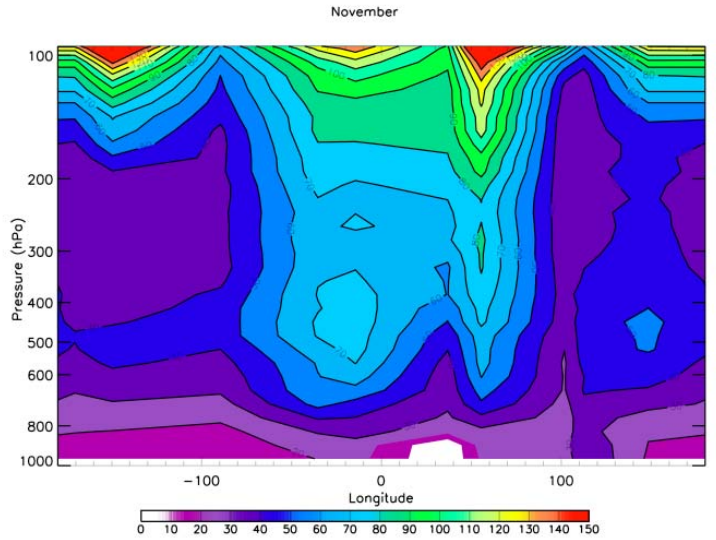
- For this study, 6 global surveys over the course of 12 days were used.
- The global survey mode for November 2004 produced 1152 observations per day spaced 5 degrees apart
- TES nadir foot print from the combined 16 detectors is 5.3 x 8.4 km
- V002 data was used for ozone and V001 data was used for CO

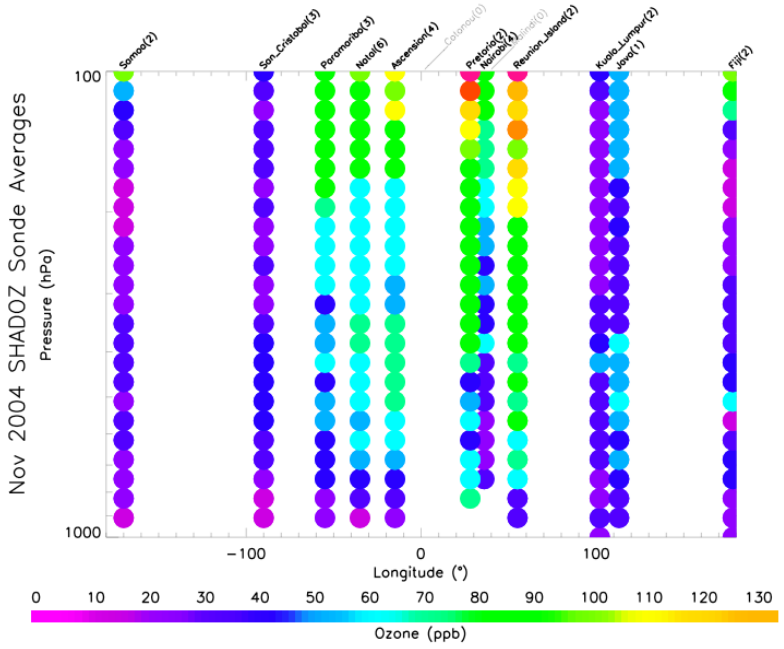
Comparison to ozone with the Shadoz network



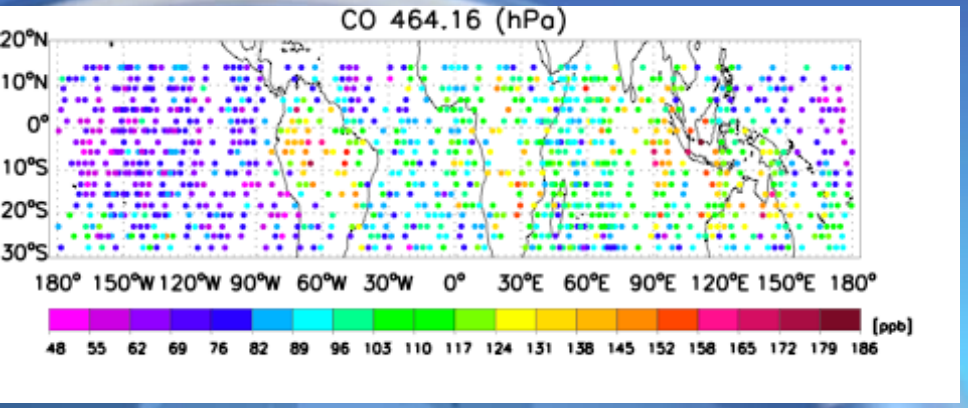
Shadoz mean of ozone was calculated
from 1998-2004 for the month of November based on 11 sites
covering a latitudinal and longitudinal range of 21S to 3N

Averages for November of 2004 are also included

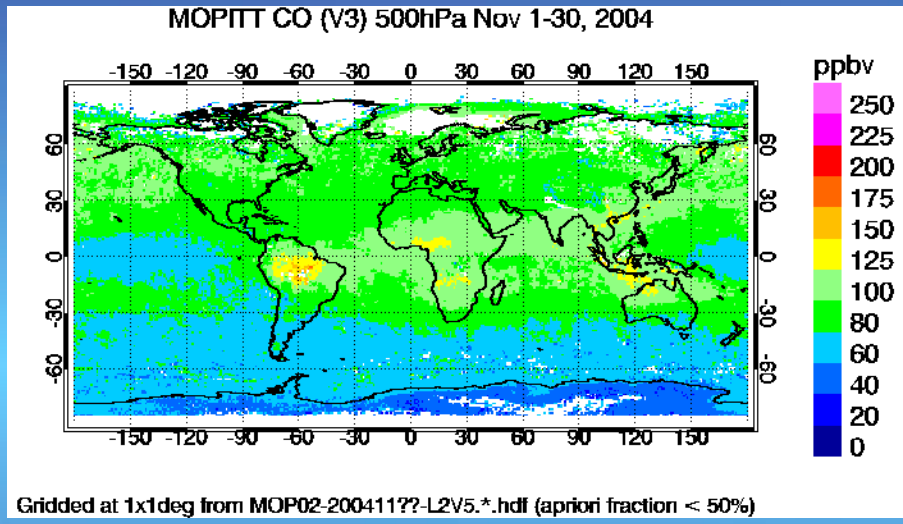




Comparison to MOPITT and AIRS tropospheric CO



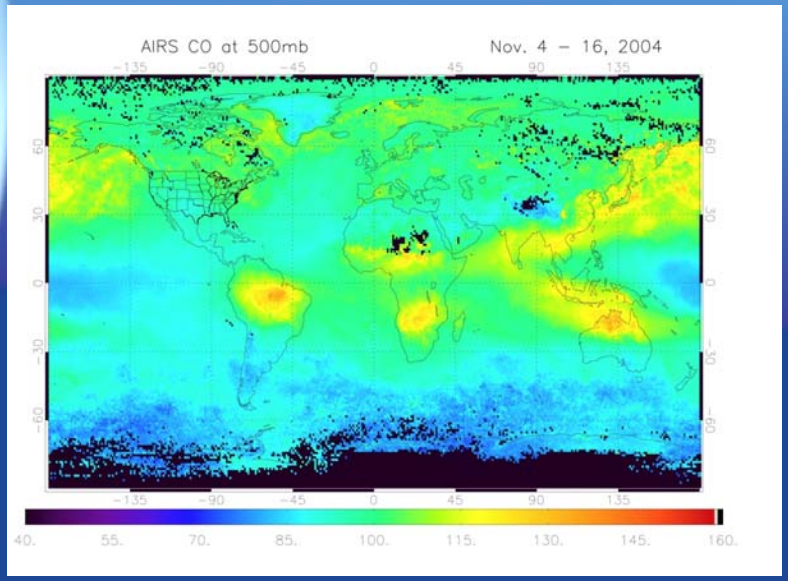
Sciamachy near-infrared CO tropospheric column estimates



MOPITT maps obtained from
http://www.eos.ucar.edu/mopitt/data/plots/mapsv3_mon.html

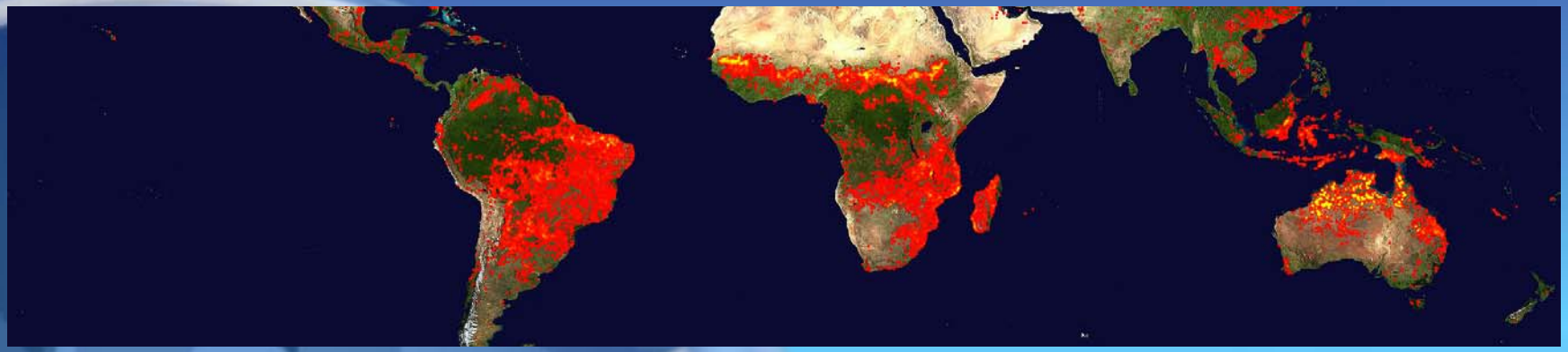
Elevated CO is observed between TES, AIRS, and MOPITT over South America, Africa, and Australia/Indonesia

A CO “plume” is observed by TES, AIRS, and MOPITT from the east of Australia extending across the south Pacific



Signatures of biomass burning

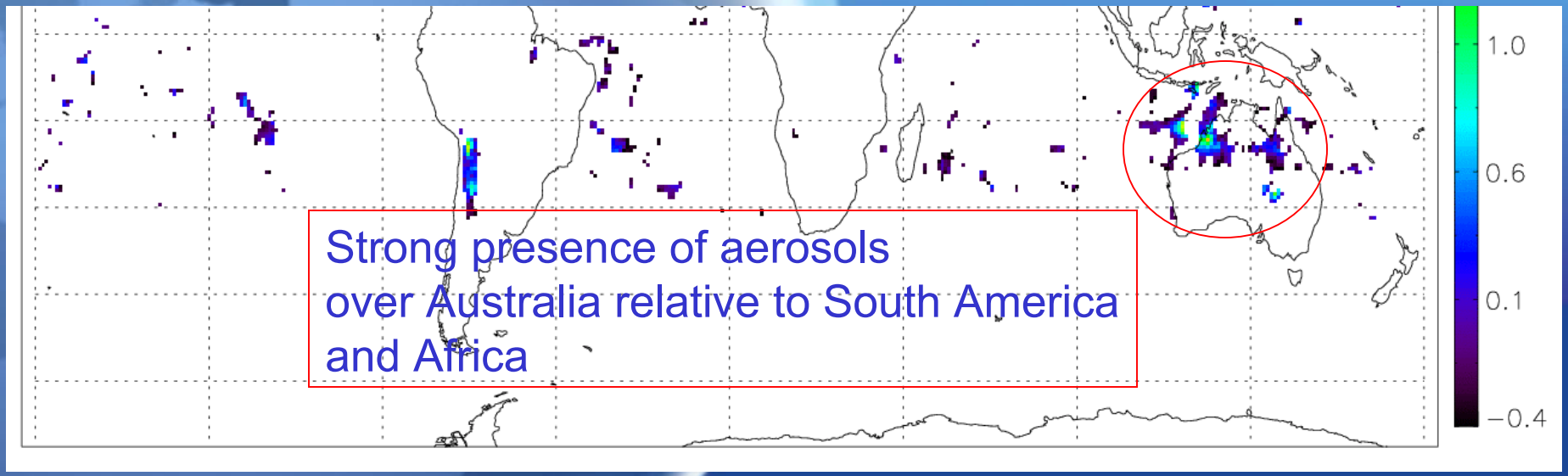
MODIS fire counts November 5-15



Red indicates at least one fire count
Yellow indicates a large number of fire counts

MODIS map obtained from
http://rapidfire.sci.gsfc.nasa.gov/firemaps/?2005211-2005220

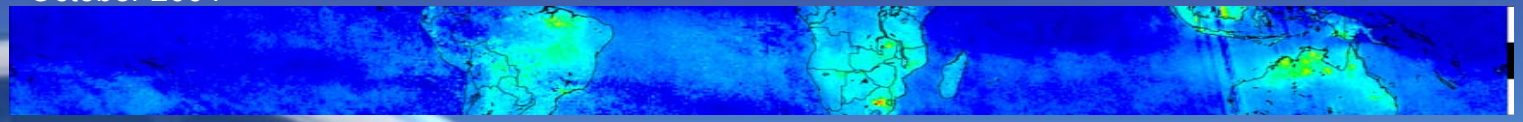
Sciamachy absorbing aerosol index (AAI) November 2004



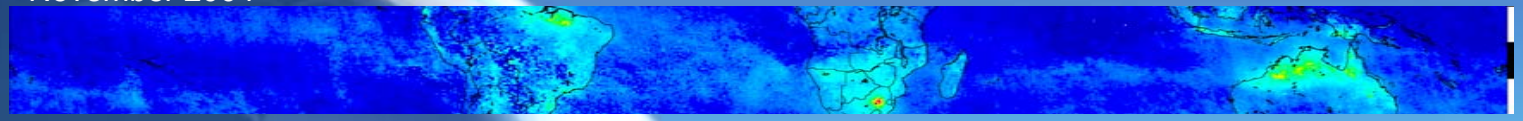
AAI maps obtained from http://www.temis.nl

NO_x signatures and distributions

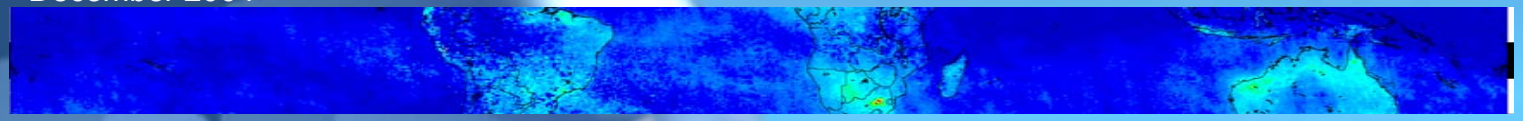
October 2004

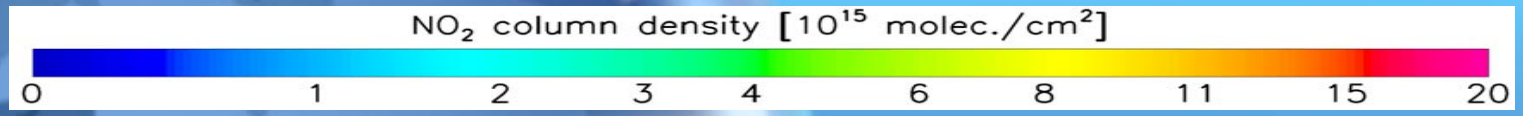


November 2004

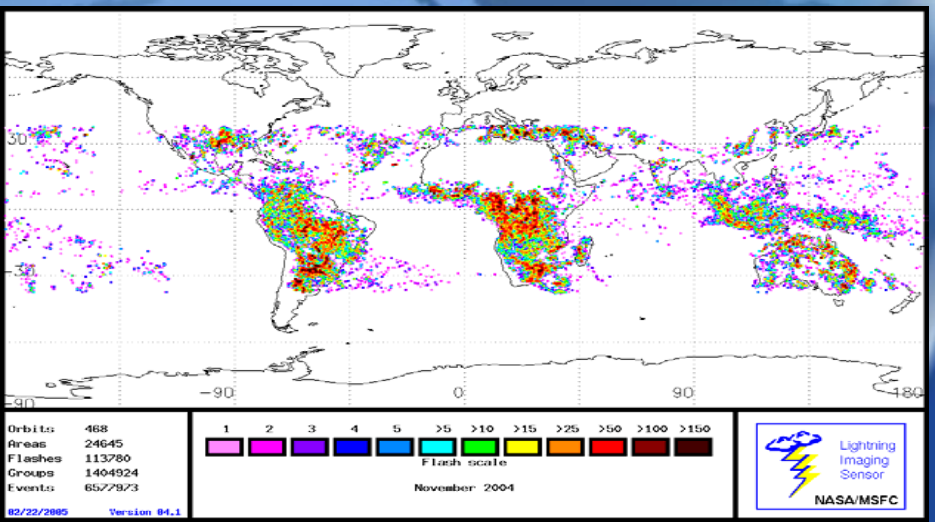


December 2004





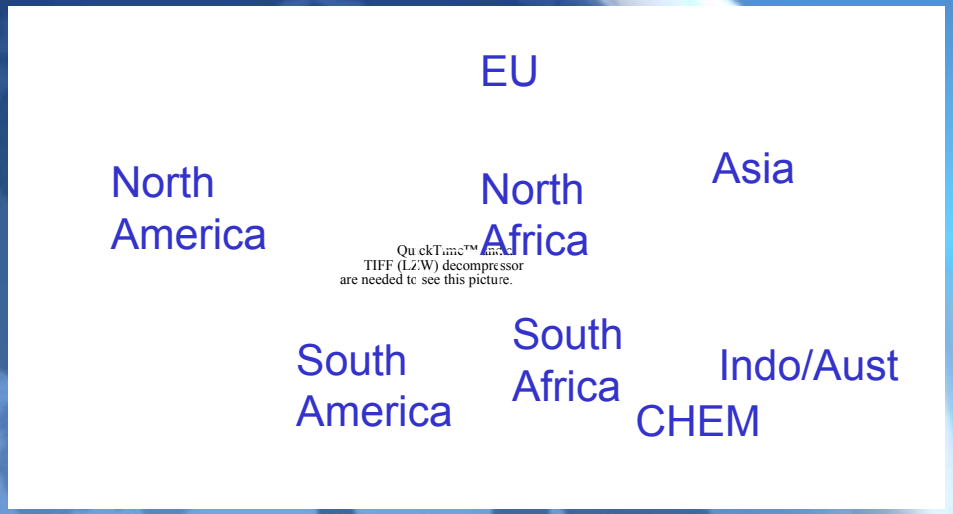
http://thunder.msfc.nasa.gov/data/query/distributions.html

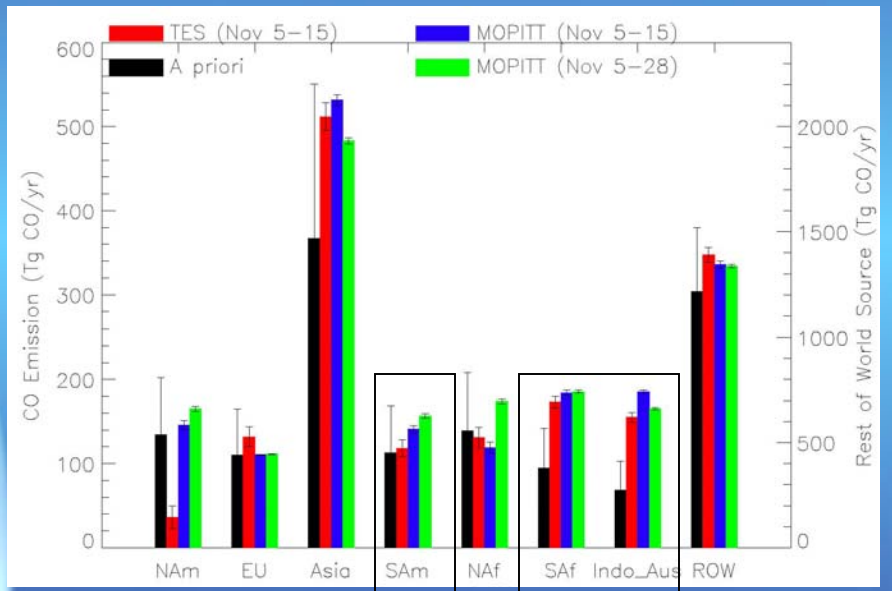


Lightning flash counts are high over South America, Africa, and Indonesia/Australia

OMI data indicates particularly high NO_2 columns in Indonesia-Australia relative sub-equatorial Africa and South America

The magnitude and distribution of surface emissions can be estimate by assimilating TES CO into GEOS-Chem through a *Maximum a posteriori* (MAP) algorithm

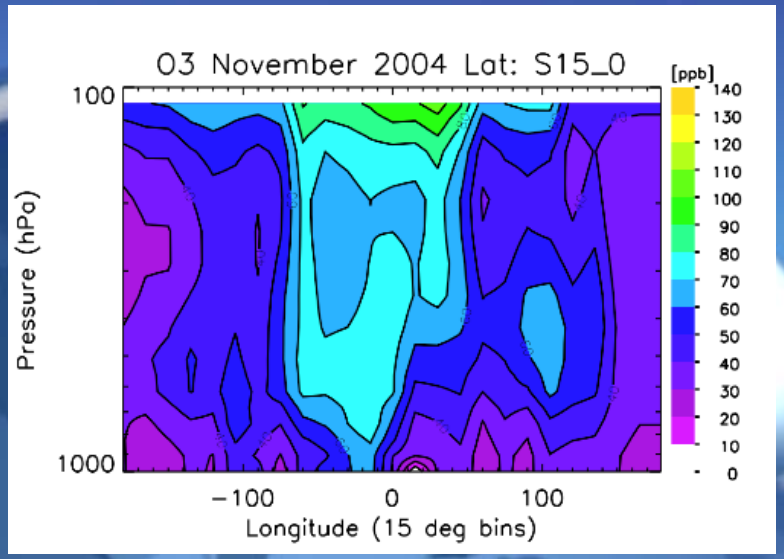


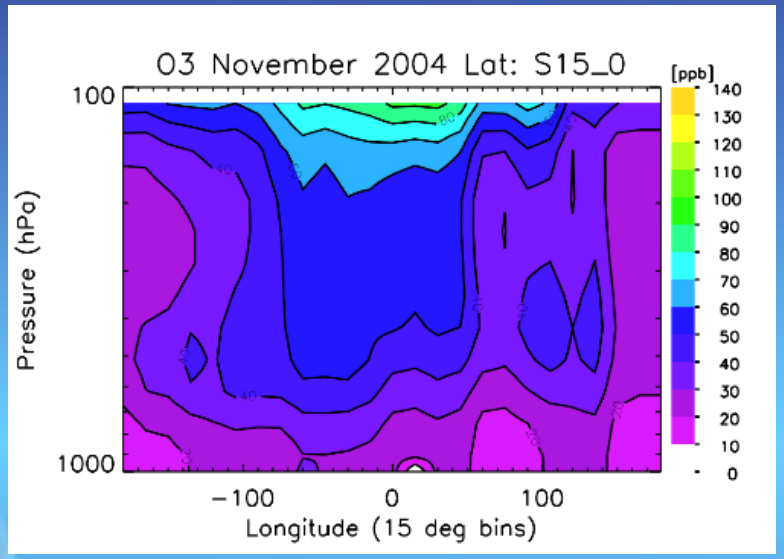


- All sources include contributions from oxidation of VOCs
- Biomass, biofuel, and fossil fuel emissions are aggregated together
- CHEM includes methane oxidation and biogenic sources
- Forward model is GEOS-Chem, with specified OH
- Assumed an a priori source uncertainty of 50% for all sources; for the background chemical source we assumed 25% uncertainty
- Specified a uniform model error of 20%

Estimates of surface emissions are a factor of 2 higher than the climatological inventory

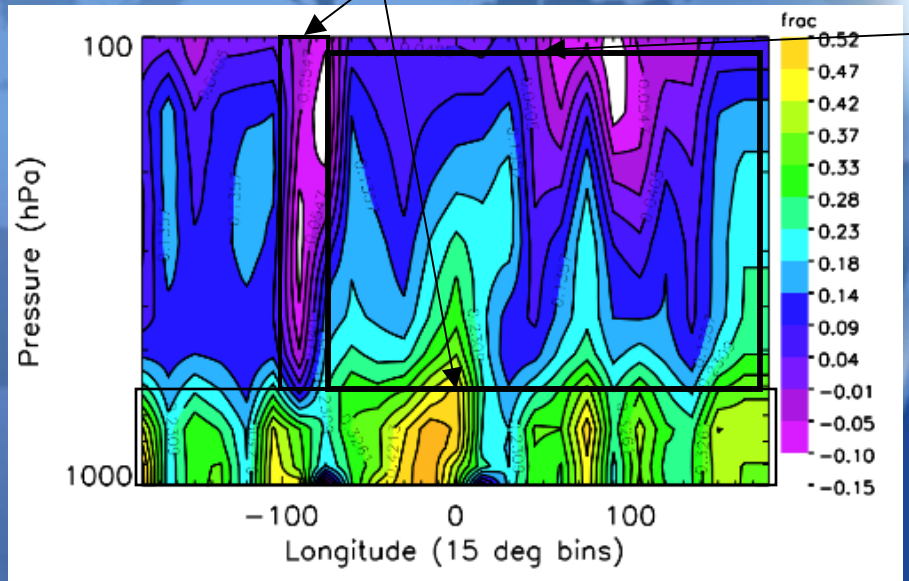
Comparison of GEOS-Chem O_3 with a posterior emissions estimates and TES observations

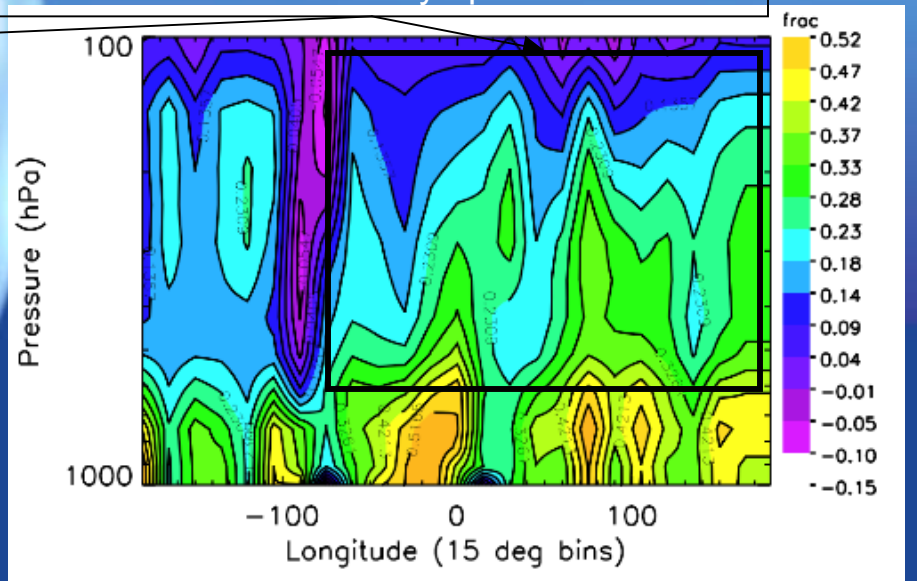




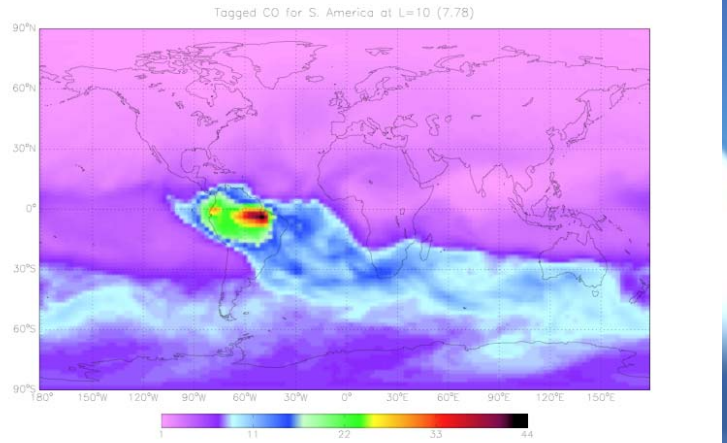
Significant areas of disagreement below 500 mb and above South America

Substantial reduction in fractional difference between sub-equatorial Africa and Indonesia-Australia above 500 mb by up to a factor of 3



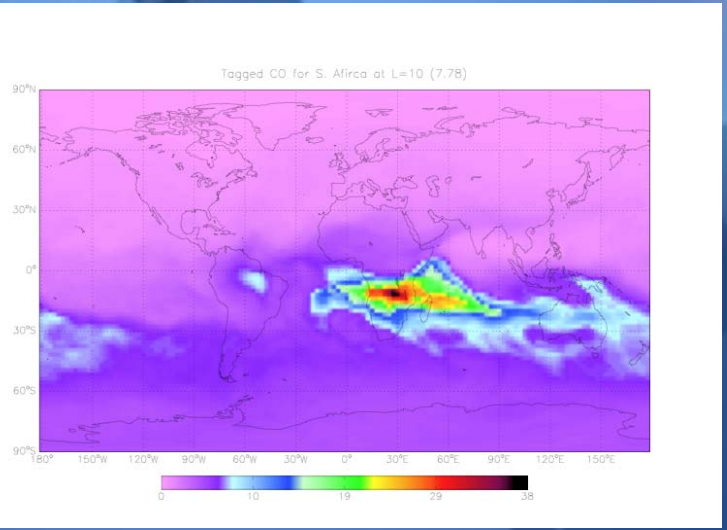


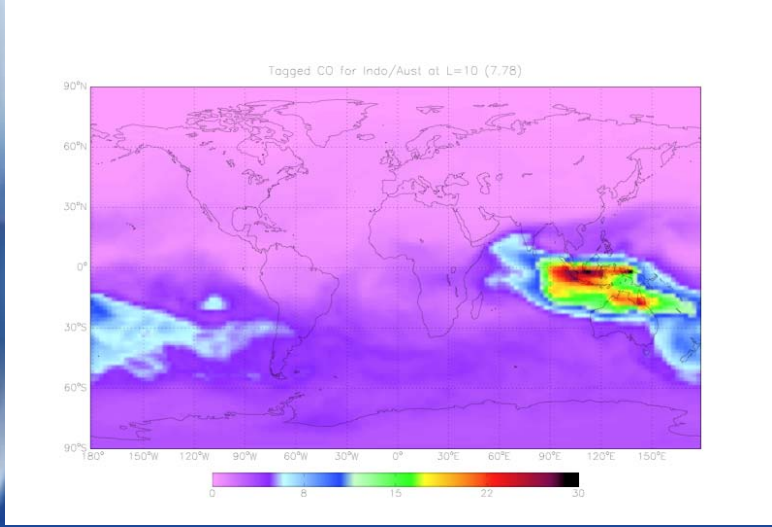
Process analysis



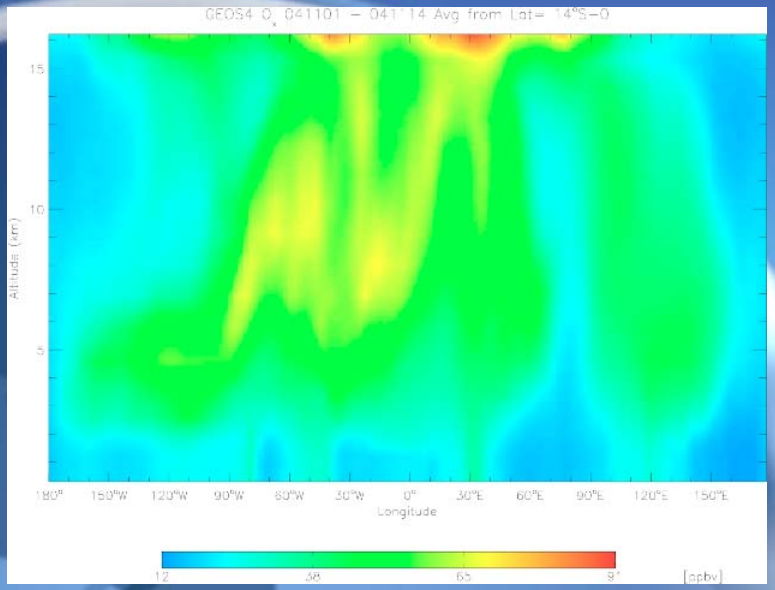
Tools used to estimate surface emissions can be important diagnostics to understand the processes controlling ozone formation

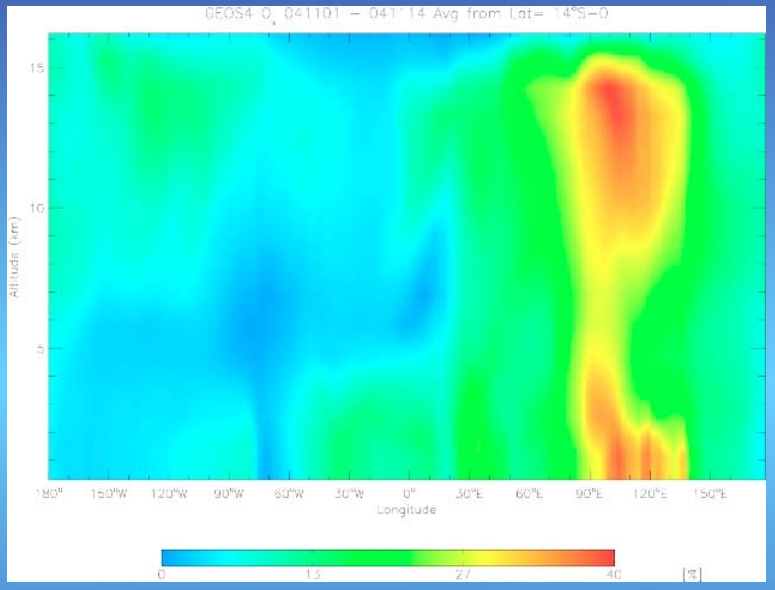
Tagged CO tracers from the 3 primary southern hemispheric continents indicate that the impact of surface emissions on ozone are fairly well separated

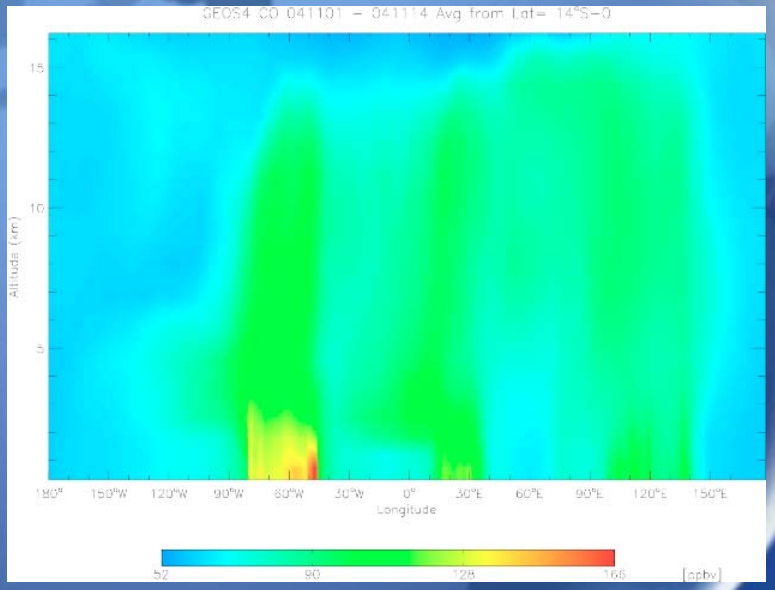


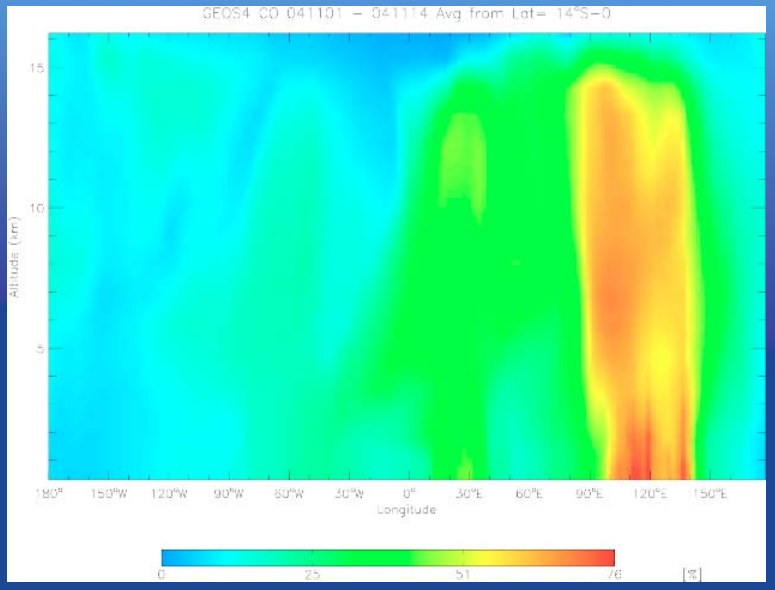


Sensitivity analysis for ozone and CO

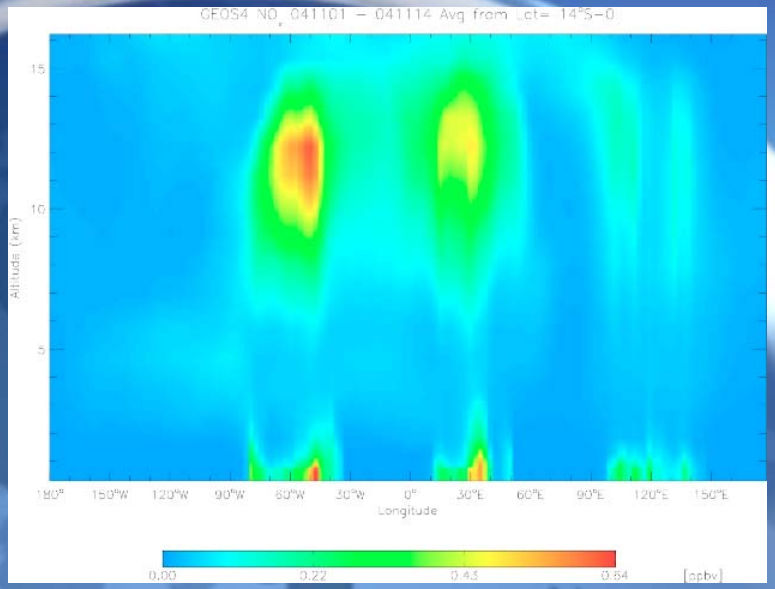


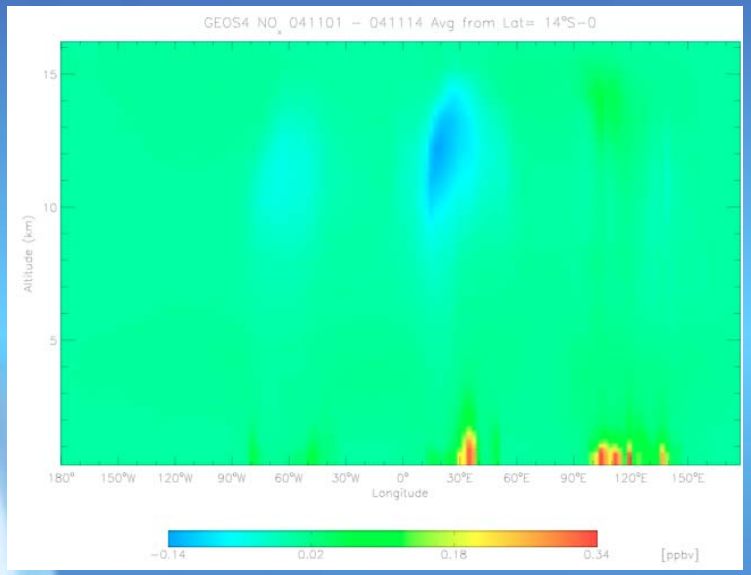


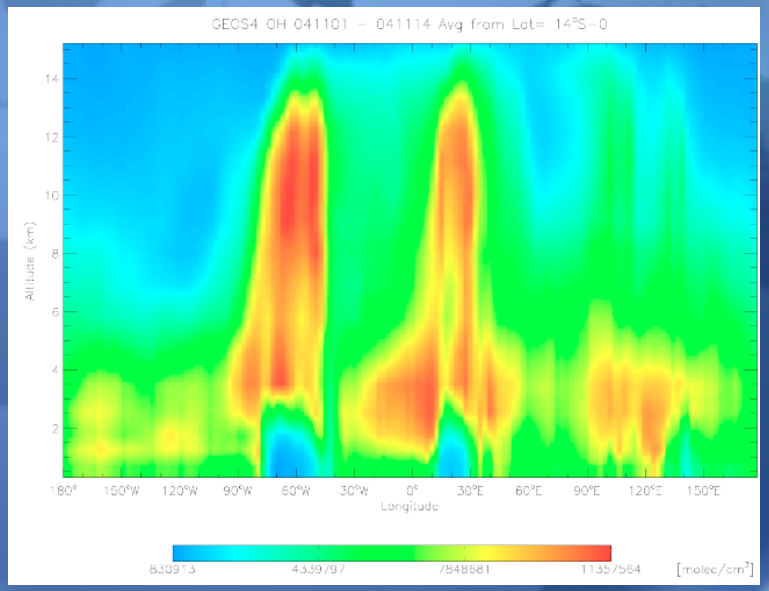


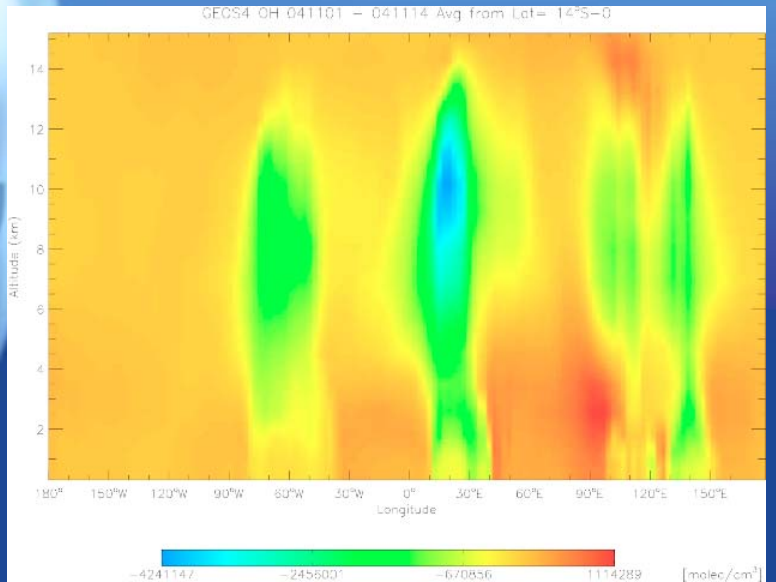


Mediating species: NOx and OH

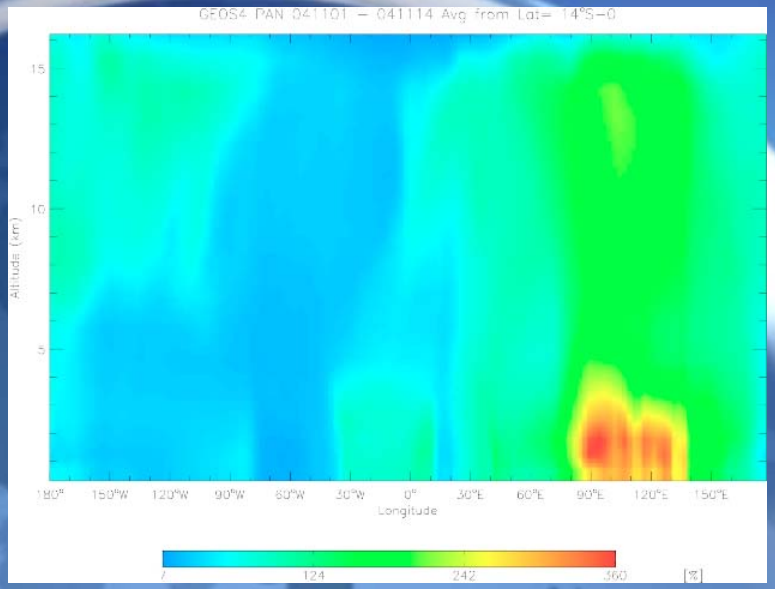


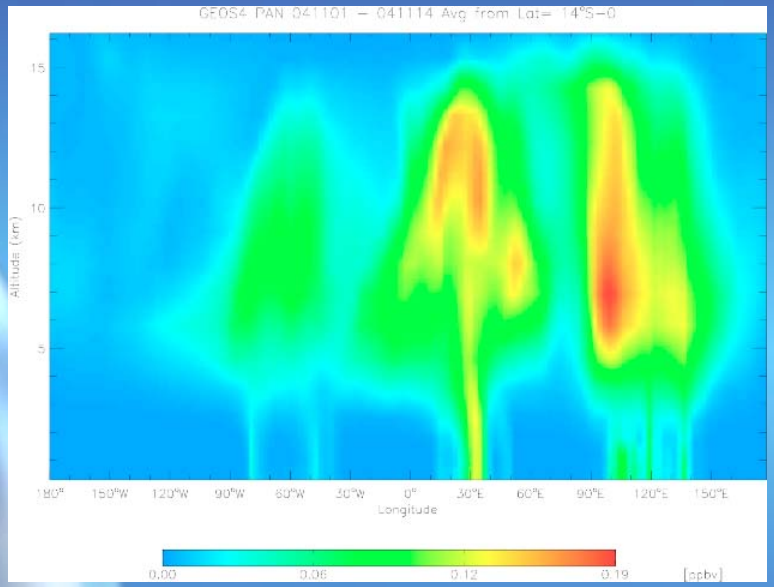


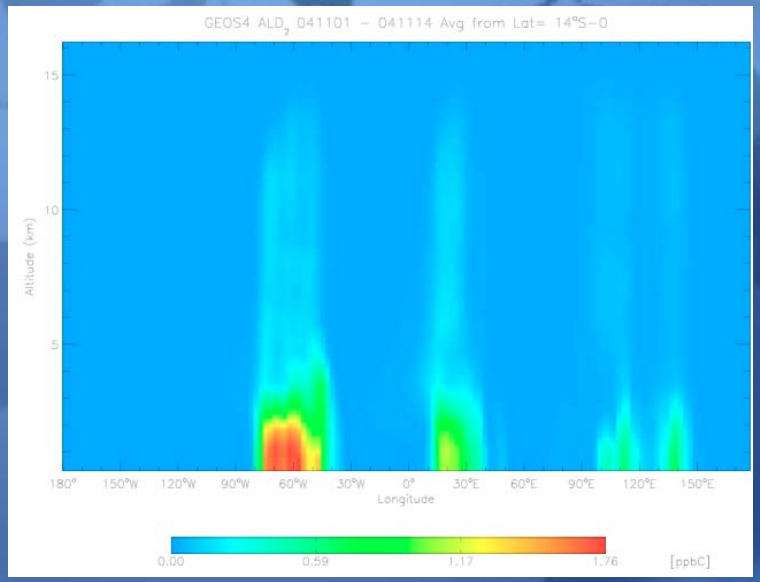


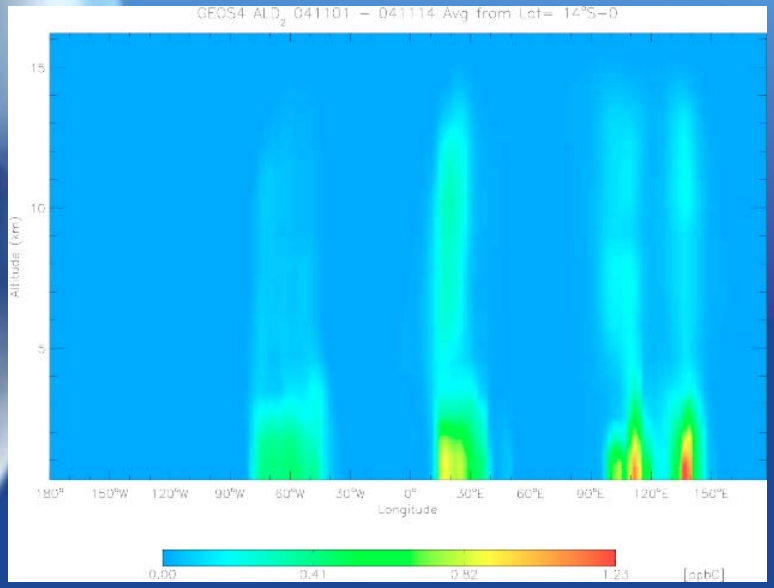


Putting PAN in its place







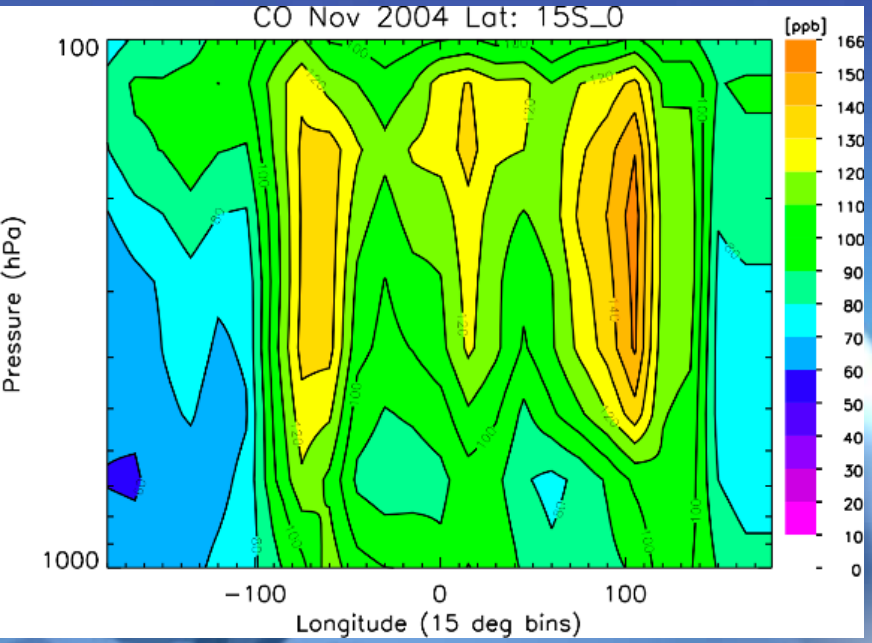


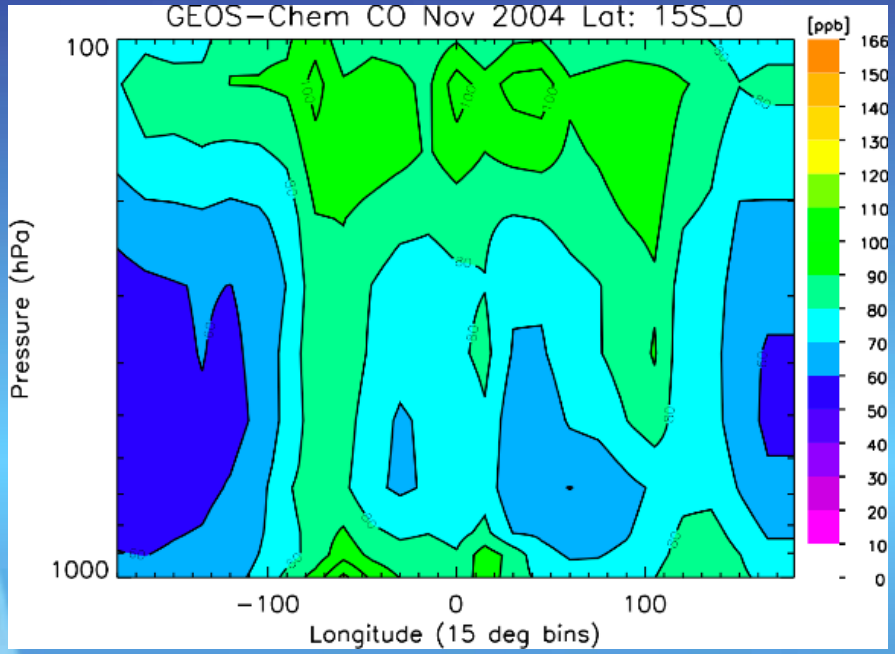
Conclusions

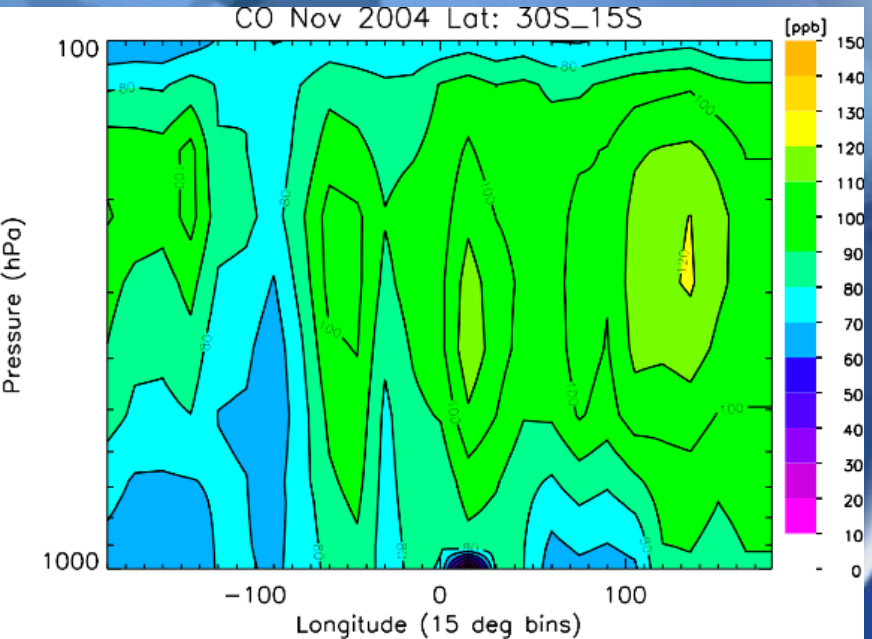
- TES retrievals show elevated ozone over the Atlantic--consistent with the "wave-one" pattern seen in the Shadoz network--as well as high ozone levels in Australia and Indonesia
- TES retrievals indicate elevated CO values over Australia/Indonesia are comparable to South America and Africa, consistent with AIRS and MOPITT CO estimates
- MODIS fire counts, Sciamachy aerosol and OMI NO_2 column measurements point to biomass burning as a source
- LIS flash counts suggest that lightning is also an important contributor of NO_x, particularly over South America and Africa
- Estimates of surface emissions from TES CO observations are up to a factor of 2 higher than climatological inventories
- Differences between TES ozone observations and *a posteriori* GEOS-Chem runs are reduced by up to a factor of 3, which suggest that surface emissions are an important contributor to ozone, particularly over Indonesia/Australia
- Sensitivity analysis can be used to investigate the key mediating processes that control ozone formation
- Advanced assimilation algorithms, such as 4DVar, adjoint analysis, Ensemble Kalman smoothing techniques will be critical for advancing the state-of-the-science in understanding the processes relating anthropogenic surface emissions to ozone variability

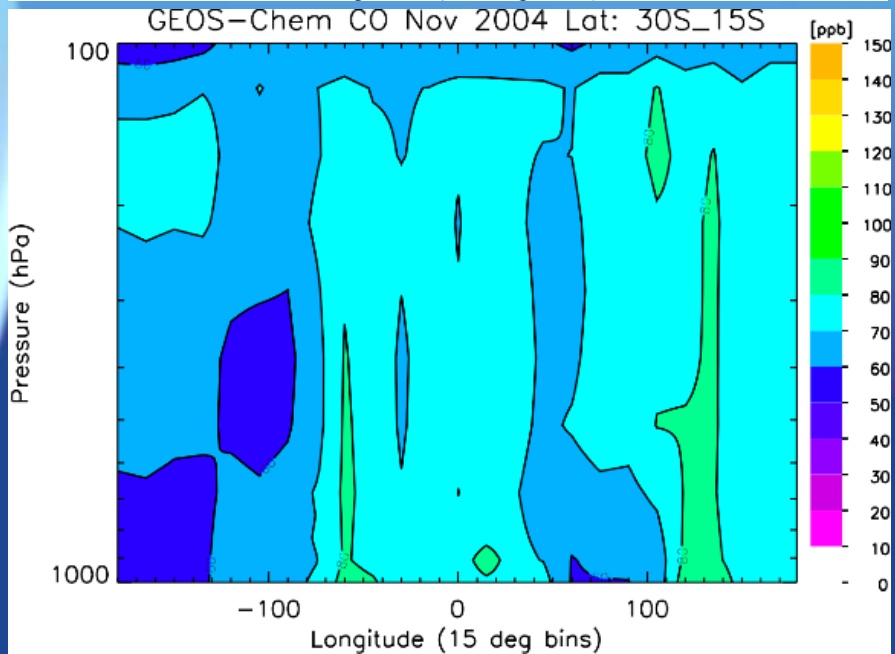

Backup slides

Comparisons to GEOS-Chem CO

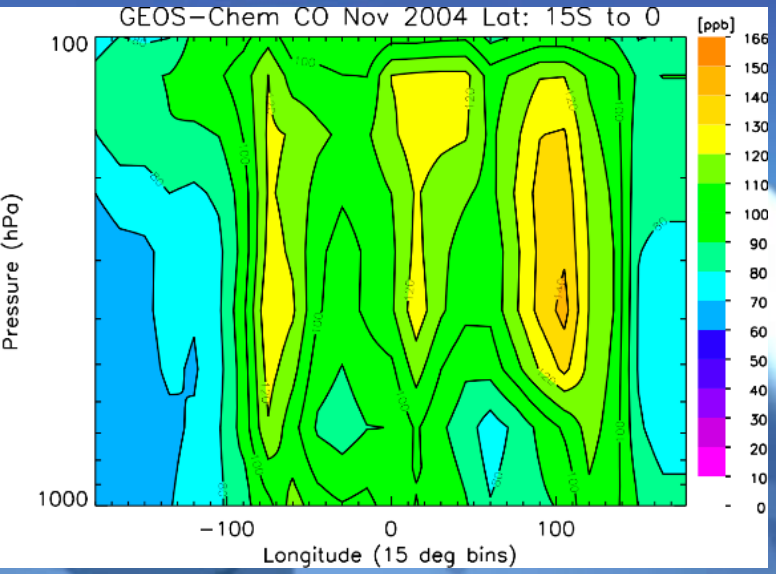


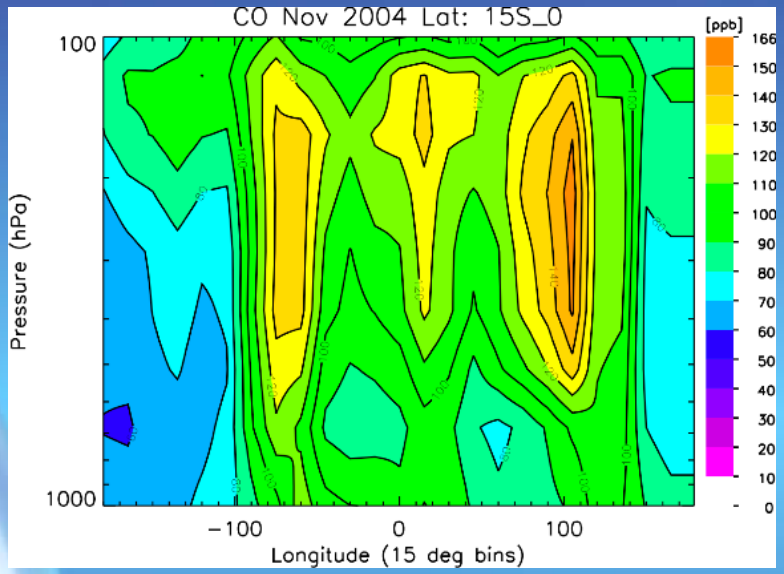


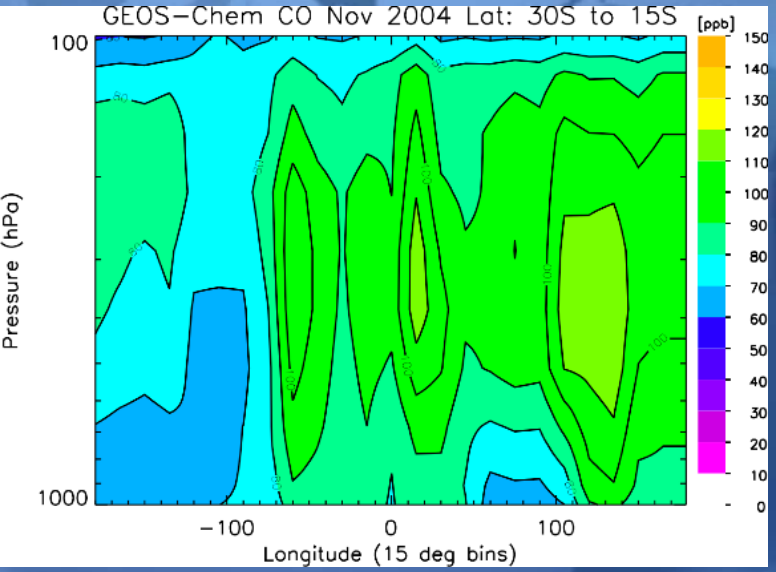


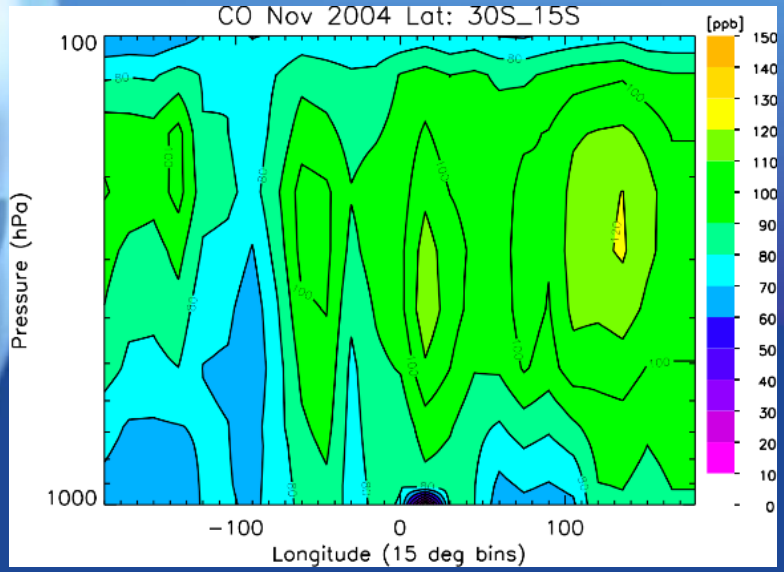


Comparison of TES to posterior estimates

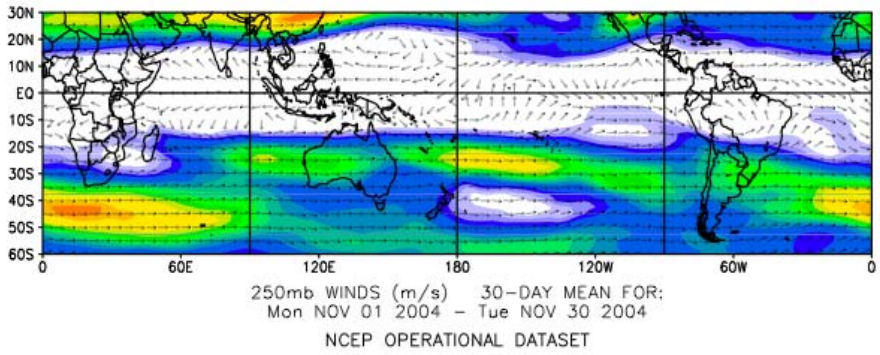








The distribution of tropical tropospheric ozone is governed by the complex interplay of chemistry and dynamics of both anthropogenic and natural origins:



Global transport through advection

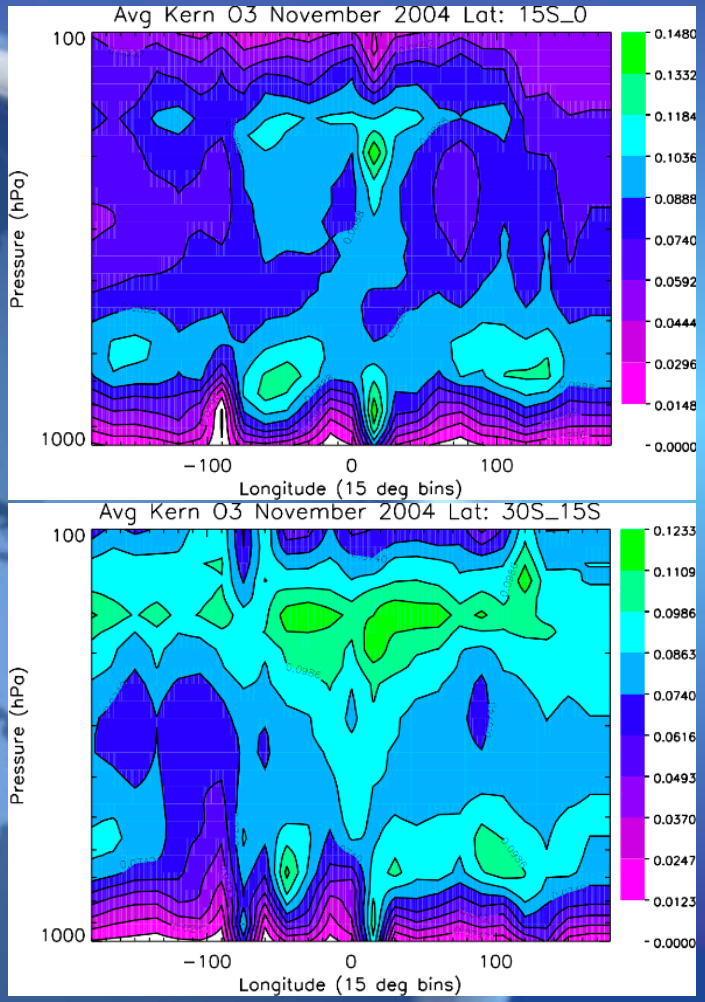
Convective lofting of ozone and precursors

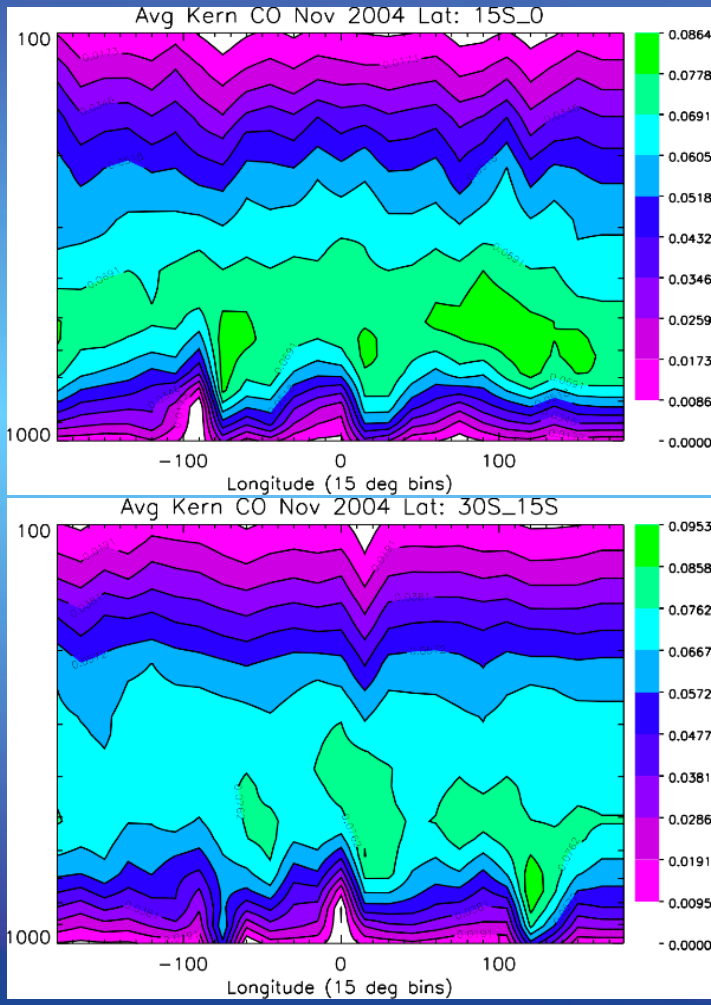
Lightning emitted NO_x

CO, NO_x , hydrocarbons, etc. are produced at the surface from biomass burning, fossil and bio-fuel emissions

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

TES ozone and CO sensitivity



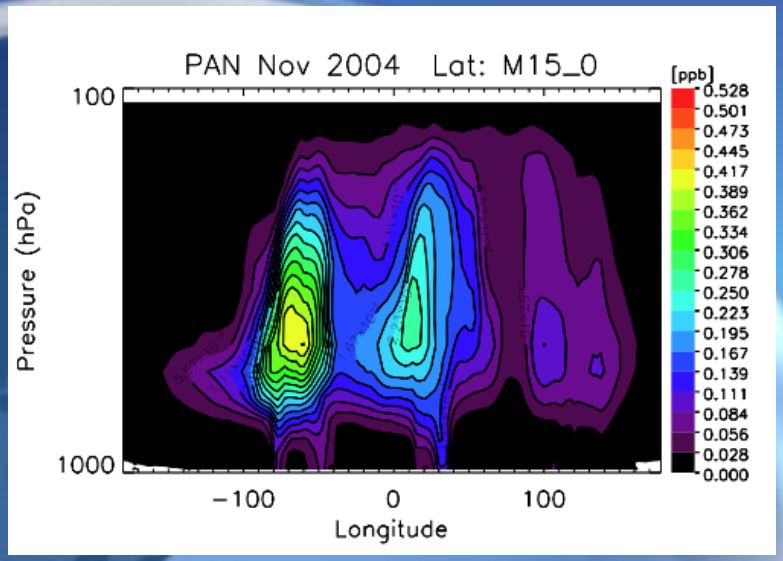


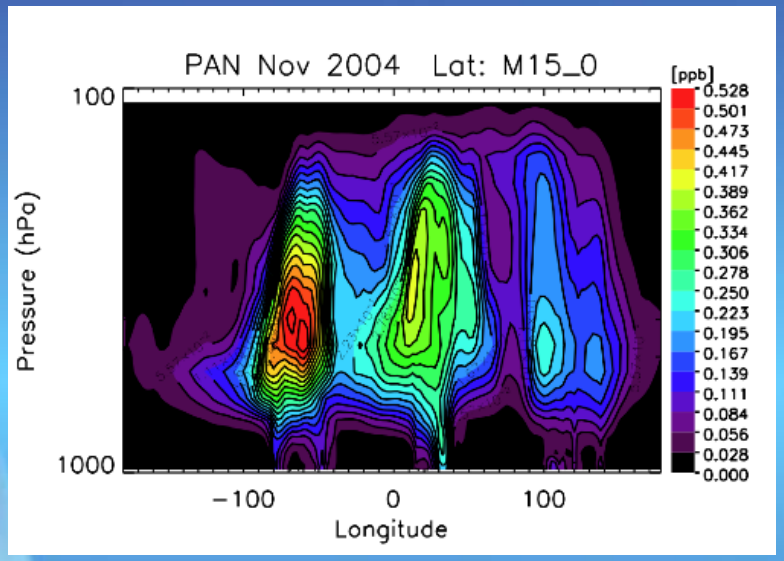
The averaging kernel is a measure of the sensitivity of the retrieval to the true state and metric for information gain

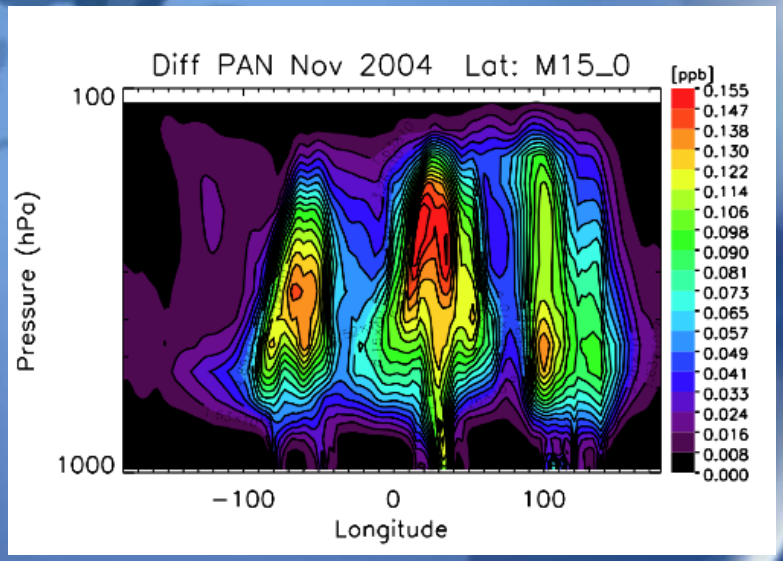
$$\mathbf{A} = \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}}$$

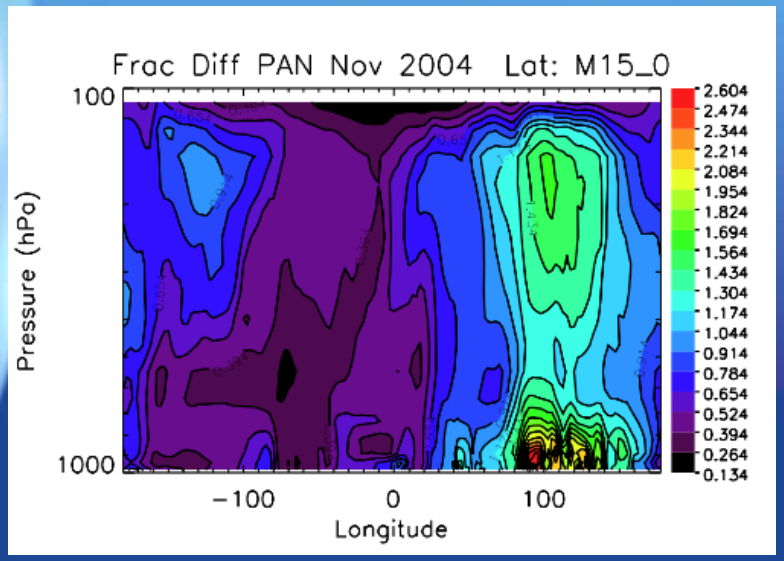
$$\mathbf{I} - \mathbf{A} = \mathbf{S}_{\tilde{\mathbf{x}}} \mathbf{S}_a^{-1}$$

Sensitivity analysis: PAN

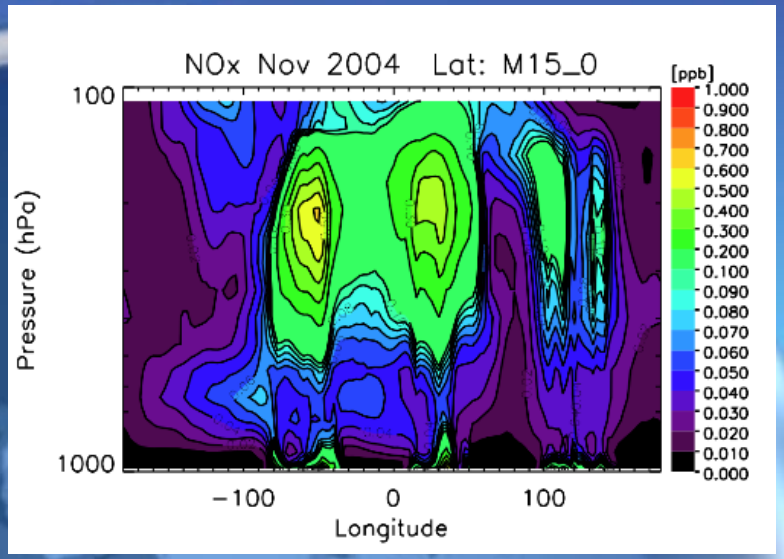


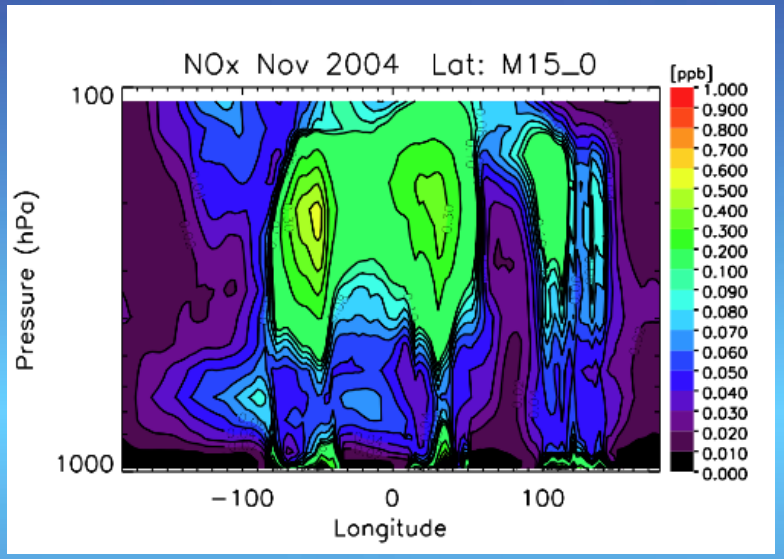


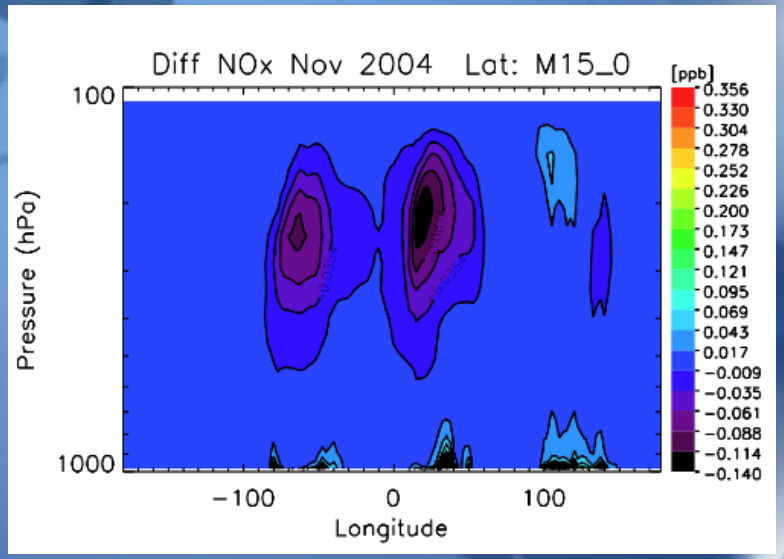


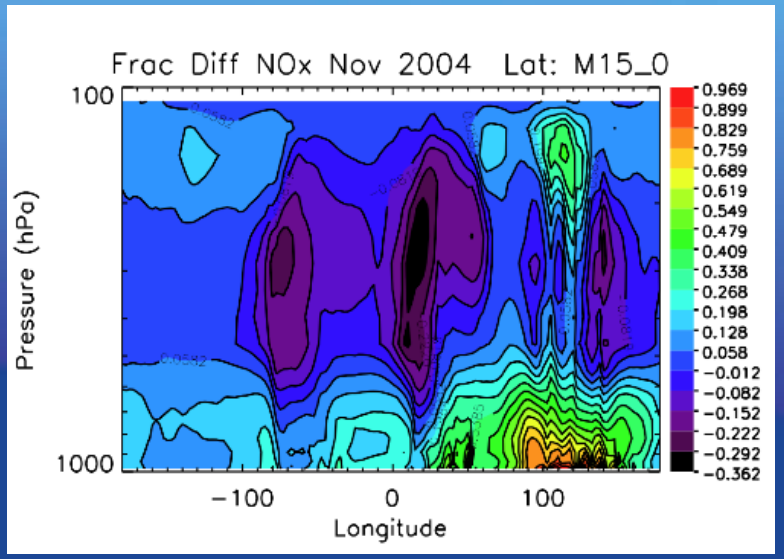


Sensitivity analysis: NOx

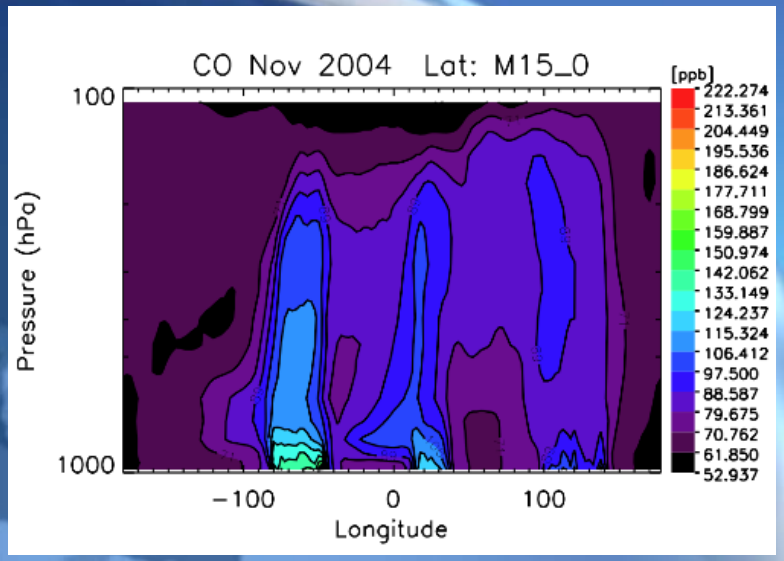


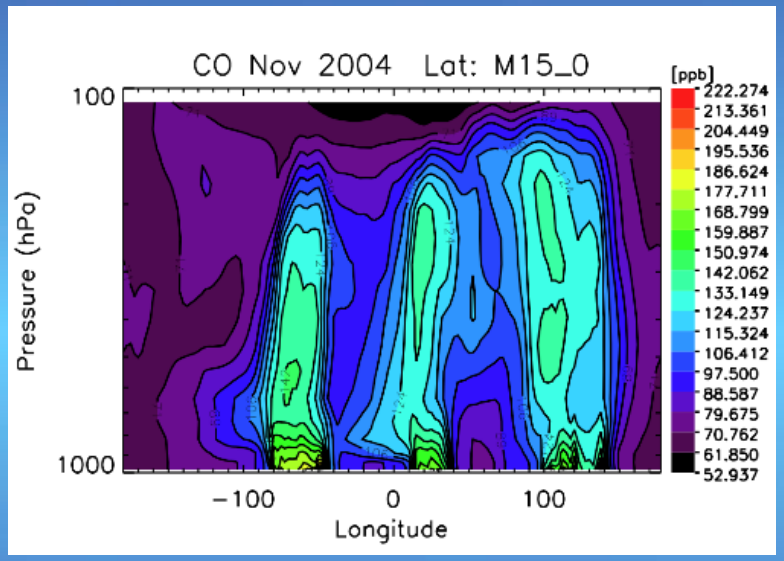


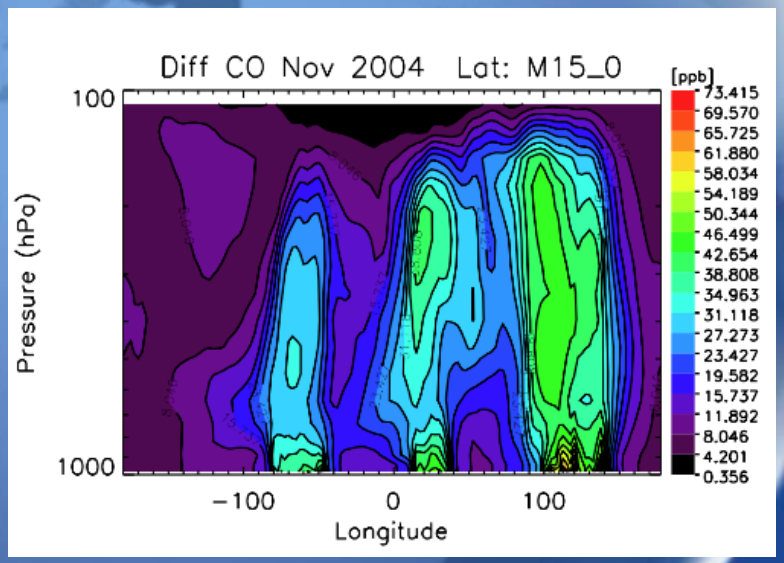


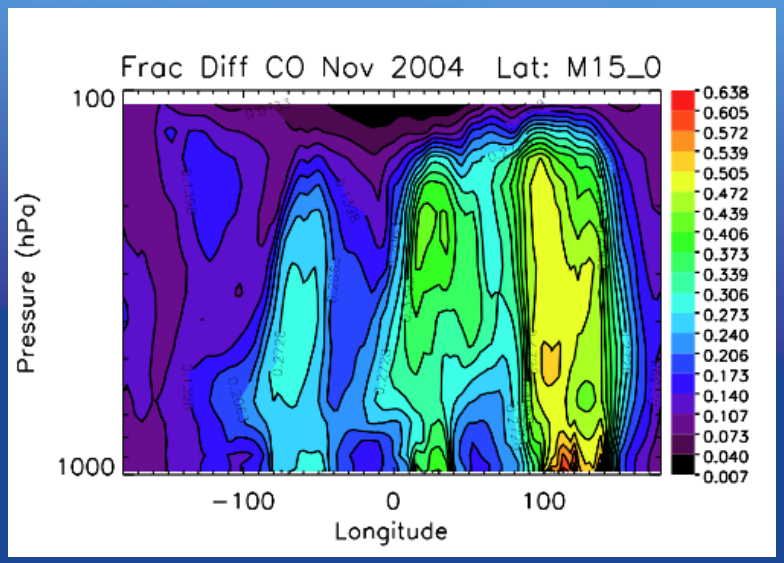


Sensitivity analysis: CO



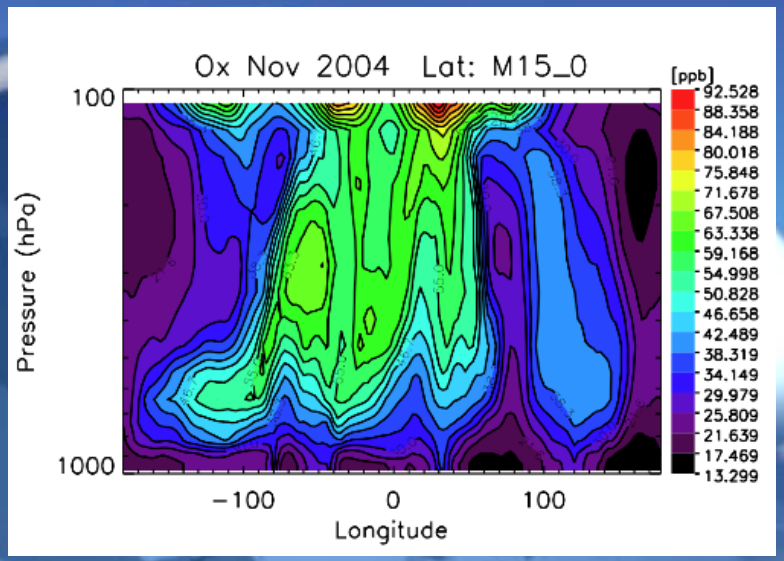






Sensitivity analysis: ozone

Prior



Posterior